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An Automated Layer Classification Method for Converting CAD Drawings to 3D BIM Models

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Abstract

In recent years, Building Information Modelling (BIM) has been pushing forwards the digitalization of global AEC industries continuously. Developing countries with low computerized level, such as China, still use CAD drawings as delivery in building project. It is significant to transform architecture drawings to BIM models in a cost-efficient way. Current researches on 3D reconstruction of architecture drawings are restricted by accuracy and automation level. In this paper, an automated layer classification method is proposed as pretreatment in transforming CAD to BIM models. It analyses the content in each layer of a drawing and classifies the layer into a specific category. Detailed methods to find out grid text layer, dimension layer, window and door layer and wall layer are presented in the paper. The approach is tested using 70 sample drawings. The average accuracy degree of classification is around 95%. Based on layer classification, the existed recognition algorithms could have better performance since obstructs are removed, and the detection method of section drawings can be optimized.

Keywords

Building information modelling (BIM) • Computer aided design • Geometric and parametric modelling • 3D reconstruction

9.1 Introduction

Building information modelling (BIM) can be served as one of most powerful technology in global architecture, engineering and construction (AEC) industry. BIM not only achieves technical breakthroughs in multi-dimensional visualization and real-time synchronization of building models, but also brings multi-disciplinary collaboration and integrated coordination throughout the project lifecycle, which consists of several main phases including planning, design, construction, operation and maintenance [1]. Currently, the application and development of BIM in some developed countries is mature including the UK, USA and Korea while in the developing countries, the development is weak, and application is limited. For

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example, in China, a survey by the D-CiTi Lab[1] indicated that less than 20% of 283 interviewed Chinese AEC industry employee have confidence to apply BIM in their project [2]. However, another report indicated that China is the top five fastest-growing regions for BIM implementation by contractors [3]. It means that there is a high BIM implementation demand in China. Currently, most of projects in China are using 2D CAD drawing as compulsory delivery and if they want to apply BIM in their project, they need to convert 2D drawing to BIM model manually. It wastes lots of time and labor cost.

In this paper, the research will investigate how to use layer information in CAD drawings to improve the current work on 3D reconstruction. An automatic method of layer classification in order to increase efficiency of conversion is presented based on current research.

9.2 Methodology

Based on the review of current architecture drawing standard, a statistic experiment through 80 pieces of real-life architecture drawings from various types of building sorts out the most frequent layer. Meanwhile, on top of the literature review of current study of 3D model converting, a structure of classification is described, and detailed methods for specific layers are given and tested through 70 drawings.

9.3 Literature Review

9.3.1 Architecture Drawing Standard

Currently, there are two main kinds of 2D CAD drawings that are commonly used in construction project [4]. One is used to present the design idea from the architect and the drawing only includes some basic components such as door, window and wall. Another one includes more information and is widely used in construction process, called construction structural drawing. In a construction structural drawing, different engineering data including the dimensions, construction object and annotation [5] are provided in both plan view and elevation view. As BIM model is still not taken as a compulsory delivery in some developing countries such as China, 2D CAD drawings are frequently utilized to convey design concept and construction instructions. When design party pass on their architecture drawings to construction party, these drawings are usually construction structural drawings, which contains rich information for engineers to understand designer's idea. One of important information in construction structure drawings is layer property, which has been neglected by the previous researches on 3D reconstruction of architecture drawings. Layer is a basic function supported in vector-based CAD system that enables to organize design information in a methodical way [4]. This function involves allocating graphical elements with identical type to the same layer, which can be switched on or off to meet the visibility and plotting requirement [5]. Compared with assigning wealthy building information on BIM family, description of each layer in architecture drawings provides fundamental information to building elements [6], such as designators, element group and status of work. Therefore, it is significant to apply layer information on the process of transforming CAD drawings to BIM model. Namely, if the family type of every geometry elements in architecture drawings can be interpreted via layer information in advance, the accuracy of recognition of architecture drawing is expected to be improved.

9.3.2 Current Work on 3D Model Converting

In the past, many construction drawings were still done on paper. Before 3D converting, these drawings need to be converted into CAD document by pattern recognition techniques [6]. With the development of CAD, most of the construction projects use digital CAD drawings to convey design information. Therefore, currently study on the 3D modelling converting are normally based on this kind of CAD drawing.

Rick Lewis and Carlo Séquin from the University of California, Berkeley [7] develop a system that can create detailed 3D polygonal building models based on AutoCAD floor plan. This system divided each kind of architectural symbols into

[1]D-CiTi Lab: Digital City Infrastructure and Technology Innovation Laboratory, a multi-million-pound living lab that integrates research and innovation on BIM and Smart City development located in the University of Nottingham Ningbo China.

dedicated layers and avoid the errors and ambiguities by correcting disjoint and overlapping edges [7]. In another research, Clifford from Hong Kong University of Science and Technology (HKUST) [8] develop an approach on the automatic wall extrusion, object mapping, and ceiling and floor reconstruction. However, above approaches still rely on manual adjustment.

Tong Lu from the Nanjing University have done many works with his team on the automatic 3D model converting based on the 2D drawing. They came up with an INDAI (Normalization of Dispersive Architectural Information) method [9] to collate the dispersed and diversified information for 3D modelling. They have also done some great arithmetic on the recognition of structural objects and recognition of architectural symbols for the 3D modelling [10]. However, the accuracy is not too high and due to the complexity of the arithmetic, and it costs some time to do the calculation. Dominguez, Garcia and Feito presented a method to extract topological information from 2D drawing [7] and use this information to reconstruct 3D model. This method depends on the detection of walls and joint point amid walls and openings, and the search of intersection point amid walls. The accuracy of this method is high. But in terms of the 3D reconstruction, it can only build the wall and floor and demands picking up corresponding layers by hand. Thus, it is a semiautomatic method. In all, Lu and Dominguez's works are state-of-art techniques. But their methods have restrictions on either accuracy or automation level.

In the current market, there are a few software companies involving in the development of 3D model converting products. For example, the Ganlanshan fast modelling software from the Glssoft, which is a Chinese software company, can covert 2D drawings semi-automatically. Users should select axis net, axis text and construction element on their own. Another Chinese company PMSbim provides a software that has similar function. Meanwhile, Handaz, a company from Egypt provides a software that can convert 2D CAD into 3D BIM automatically, but the layer and block still need to be selected manually. These commercial software also have a common drawback. They don't recognize the section view. As a result, some positions of the elements such as window, door and stairs can be misplaced and need to be corrected by hand.

From the above review, the automaticity, accuracy and the simplicity of the current studies and products need to be improved. In this paper a layer classification method for 3D model converting is presented to solve the limitation of current work on 3D model converting.

9.4 Automatic Layer Classification Method

9.4.1 Layer Property in Construction Structural Drawings

To systematically analyze the principal of relating layer property to architecture drawing recognition, the standard of layer naming format and content is to be determined first. There are already numbers of international and national CAD standards which make specifications or guidelines for layers [4, 6]. However, after viewing 80 pieces of real-life CAD drawings, it is found that most of construction structural drawings didn't follow the rules of national or international CAD standards. For example, the layer containing wall elements is predefined to be named "A-WALL-FULL-TEXT" in AIA CAD Layer Guidelines [4], which indicates "Architectural, Wall, Full-height, Text" [4]. In real-life drawings, this layer is usually simply named "WALL" or "A-WALL". This phenomenon results from the following reasons. (1) The national CAD standard for construction industry in China is not complete, and government has not requested design institutes to follow any international standards. (2) More CAD standards are at enterprise level. Namely, the specification of layer varies among different design companies. Hence, it is not reliable to determine the content of an architecture drawing layer according to international or national standards. This paper uses statistics method to induce the common characteristics of layer in real-life

Table 9.1 Frequently occurred layers in sample 2D CAD drawings

Layer name	Occurrence rate (%)	Content
AXIS_TEXT	100	Consist of texts, representing reference of grid lines
BK-LINE, DOTE	100	Consist of lines, representing grid lines
Wall, A-WALL	100	Consist of lines, representing walls
WINDOW	100	Consist of arcs and lines, representing windows and doors
PUB_DIM	100	Consist of texts and lines, representing dimension notations
WINDOW_TEXT	100	Consist of texts, representing type specification of nearby doors and windows
STAIR	93.75	Consist of lines, representing stairs and elevators

CAD drawings. In detail, 80 pieces of CAD drawings from 10 design companies are studied, and the most frequently occurred layers and corresponding content can be shown in Table 9.1.

From Table 9.1, it can be seen that each fundamental component in a building design, such as wall, door and window, always reside on a particular layer excluding other components. The name format is not unified but the content of layer is conserved. Consequently, it is not creditable to identify what component is placed on a layer by the name of layer. Instead, the feasible solution is analyzing the geometric and semantic content in a layer to realize what this layer describes. An automated layer classification method is thus proposed to classify the property of layer in 2D drawings.

9.4.2 Overview of Automated Layer Classification Method

Previous recognition systems focuses on detecting architecture elements based on their geometric constrain [7–9], topology characteristics [10, 11] and semantic relationship [12–14]. Whereas, these information can also be adopted to identify layer property in architecture drawings.

The classification starts from searching feature elements (FE) in each layer. Feature element is the most distinguishable and representative element with regards to a structural object or annotation. From Table 9.1, it can be found that FE of wall is line, while FE of door and grid text are arc and text separately. Next, the attribute of FE should be checked whether it satisfies some conditions. A FE will have larger possibility to match a targeted category if the attribute of FE accords with characteristics of that object. Apart from self-attribute of FE, the surrounding environment of FE is another essential factor to determine the match degree to an object. The nearby elements that have relational constrains to feature elements are named "related element" (RE). Same as FE, the attribute of RE is also required checking. Moreover, the relationship between FE and RE should meet kinds of criteria. Considering the complexity of shape and topology of some members in architecture drawings, a FE might have multiple related elements, and a RE can also possess related elements if topology of RE should be explored.

Due to the otherness of drawing conventions [7] and variety of design, some conditions used to judge attribute and topology relationship of FE and RE are strict, while other conditions are weaker with less influence on the result. For example, an exterior wall is always drawn as two parallel lines, and thickness of a wall often lies between 100 and 300 mm. Hence, the parallel relationship between FE and RE is a strict condition to identify whether FE is part of wall lines, but the distance between FE and RE is not rigidly limited within [100, 300] because there exist walls exceeding this range. Therefore, the condition can be divided into two types: necessary condition (NC) and sufficient condition (SC). Necessary condition suggests that only the condition is satisfied can the FE stands for targeted structural object or annotations. On the other hand, sufficient condition is not a necessity to determine whether a FE is describing the targeted object, but the likelihood is increased if such condition is met.

Figure 9.1 presents a basic structure of automatic classification method, where Attr denotes attribute and Rel denotes topology relationship between element and its preceding element. When distinguishing whether a tested layer belongs to a targeted category, every FE and it's corresponding RE should be evaluated in the tested layer. All the necessary conditions in each group of <FE, RE1, RE2…Ren> should be checked prior to sufficient conditions. Provided that all NC are passed,

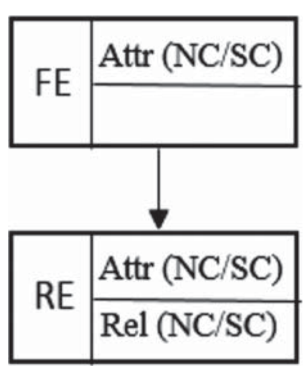

Fig. 9.1 Basic structure of automatic layer classification method

sufficient conditions are subsequently verified. The result is reflected by a score, which implies the probability that the testing FE is describing the objective category.

$$Score = \begin{cases} 0 & (\exists NC == False) \\ \frac{N(SC==True)+1}{N(SC)+1} & (\nexists NC == False) \end{cases} \quad (1)$$

The formula of calculating score of a FE is shown above, “N(SC == True)” indicates the number of satisfied sufficient conditions. Both numerator and denominator are added 1 in case that the number of sufficient conditions in some special categories is zero. Once the score of every FE in a layer is computed, the total score to assess the probability for a layer to match targeted category can be derived:

$$Total\,score = \sum_{N(FE)}^{i=1} Score(i) \quad (2)$$

At the end, the layer with the largest total score with regards to one category is selected, which is recognized that this layer is most likely to contain demanding structural objects or annotations. The entire procedure of layer classification method can be formalized in algorithms shown below.

Algorithm1 **ALCM:** Automated layer classification method	Comment
Input:	
adwg	//The test architecture CAD drawing
tglayers	//The target layers for classification
Output:	
rlayers	//The result of classification result consisting of part of layers in adwg that is recognized as target layers.
procedure ALCM(Adwg, tglayers)	
alayers ⟵ getLayer(adwg) ;	// get a list of layers of input drawing
foreach tglayer **in** tglayers **do**	// loop every target layer in tgLayers
tgFE ⟵ getFeatureelement(tglayer) ;	// get feature element of target layer
tgRE ⟵ getRelatedelement(tglayer) ;	// get related element of target layer
foreach Alayer **in** Alayers **do**	// loop every test layer in alayers
foreach tgFE **in** Alayer **do**	// loop every FE in test layer
if checkNC(tgFE) = true **then**	// check if all necessary conditions of FE are met
foreach tgRE in Alayer **do**	
if isConnect(tgFE, tgRE) = true **then**	// check if tgRE is related to tgFE
if checkNC(tgRE) = true **then**	
TSC ⟵ checkSC(tgFE,tgRE) ;	// check all the sufficient conditons of FE and RE, and count numbers
else continue;	
else continue;	
score ⟵ calculateScore(TSC) ;	// calculate score
totalscore += score ;	// add score to total score of alayer
else continue;	
if totalscore > maxscore **then**	// check if the total score of current test layer is the largest score; if so,
rlayer ⟵ alayer ;	the target layer match current layer
rlayers +=rlayer ;	// append classified layer to output result
return rlayers;	

The above Pseudocode provides a general description of how automatic layer classification works. The output is a list of layers in CAD drawings that correspond to target layers. The functions checkSC and checkNC vary in structure and procedure depending on particular target layer. Therefore, NC, SC of each layer requires verified.

9.4.3 Detailed Method to Classify Typical Layers

In the previous section, the basic framework of classification method is introduced. Based on this framework, detailed method to classify demanding layers is presented, and the content of FE, RE, NC and SC specific to each category is discussed. In this paper, the proposed automated layer classification method will discern 4 of the most frequent layers from

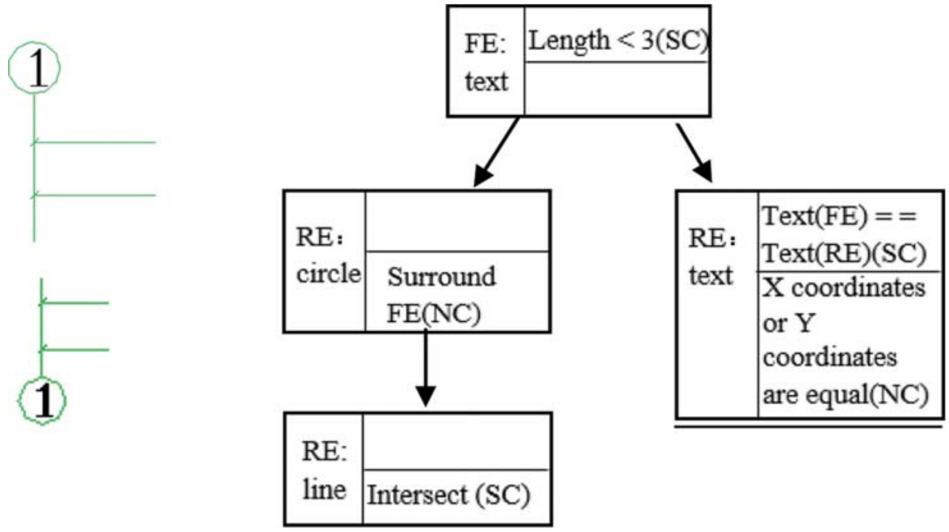

Fig. 9.2 Example of axis text and its layer classification method

statistics result, which are axis text, dimensions, walls and doors layers, and assumption is made that there is only one layer existed for every targeted category in a piece of 2D drawings.

9.4.3.1 Axis Text Layer

Axis text is a group of strings consisting of pairs of number or letter in 2D drawings, which express the label of grid lines. Filtering out the layer of axis text is meaningful to reconstruct grid nets. Apparently, FE of axis text is text, of which the attribute should take string length into account. Usually axis text is made up of short words like "1", "A" or "1-1". Therefore, a sufficient condition can be set that the string length is less than 3 characters. The related element of FE is circle. It is a fixed drawing convention that a grid text should be placed into a circle [15]. This rule forms a necessary condition in terms of topology relationship of RE. Furthermore, there is usually a line connected with this circle, which can be taken as SC. Another RE is text because there are always same axis texts at both ends of a grid line, and these two texts always rely on a horizontal line or vertical line. However, it is observed that not all grid lines have two corresponding axis texts. So whether there is an identical text in the layer becomes a sufficient condition (Fig. 9.2).

9.4.3.2 Dimension Layer

Dimension in CAD drawings shows the size of structural members or grid nets. As Jensen explained [16], a dimension is mainly composed of dimension lines, extension lines and text. In CAD drawings, there are additional two oblique short lines at both ends of dimension lines to illustrate the scope of a dimension. The key problem in recognizing dimensions is figuring

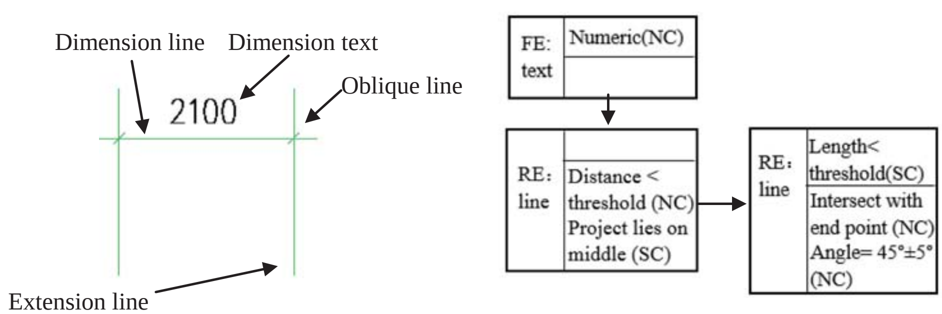

Fig. 9.3 Example of dimension and its layer classification method

out the correct dimension text for a dimension line [14]. Dimension text is not permanently written at the center of dimension line. Moreover, the distance between dimension text and its related dimension line might not be the least distance compared with other texts. Therefore, with the influence of existence of other numbers such as elevation in 2D drawings, mistakes would occur in matching dimension text and line. FE is chosen to be text implying dimension text rather than dimension line for the sake of less computation cost. It is necessary for FE that the text should be a numeric number because it represents size of an object. Next, RE is line implying dimension line. The distance between FE and RE should be less than a threshold. A sufficient condition is that the projection of FE on RE is at middle part of line since dimension text usually stays at center of a dimension. The related element of dimension line is oblique line. It must intersect with end of dimension line and angle between them should be around 45°. The length of this RE should be smaller than a threshold for the oblique line is always short (Fig. 9.3).

9.4.3.3 Window and Door Layer

In 2D drawings, window members and door members are plotted in the same layer. Hence, decision should be made that the feature element is picked up from window symbol or door symbol. Yin et al. [17] pointed out that designers are not used to obey a particular standard in terms of shapes of window and door. In fact, the drawing style of these symbols comes from architecture's artistic motivation, which makes the extraction of FE difficult. In order to study the common characteristics of these shapes, 80 pieces of 2D drawings are reviewed. As presented in Figs. 9.4, 9.5 and 9.6, it can be concluded that variance of window symbol is larger than that of door symbol. Moreover, in some 2D drawings, window is simply delineated as a rectangle, which is easily misunderstood as a wall. In contrast, door symbol has more static geometry constrain and representative elements. Consequently, FE of window and door layer is chosen to be arc from door symbol. Some sufficient conditions are applied on the attribute of FE. The angle of arc needs to be approximately 90° while the radius should range from 0.6 to 1 m, which is common value of width for single-flush door. The related element is line with similar length with FE's radius. For the sake of imitating the basic fashion of a door, the topology relationship of RE with regard to

Fig. 9.4 Different shapes of window in real-life 2D drawings

Fig. 9.5 Different shapes of door in real-life 2D drawings

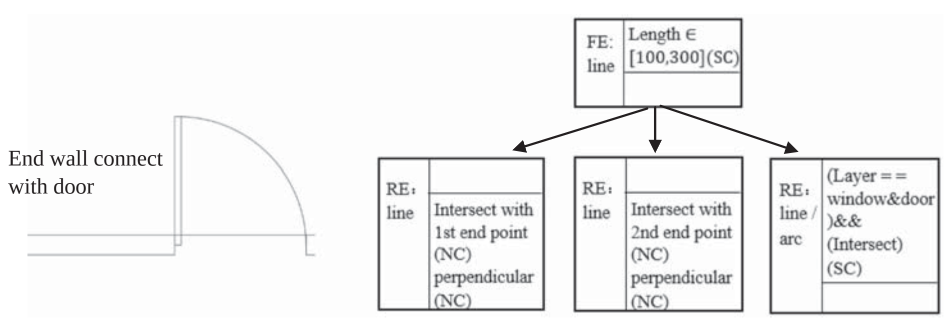

Fig. 9.6 Example of wall and its layer classification method

FE can be summarized as two conditions. A necessary condition is that RE must connect with either end of arc. Another condition is a sufficient condition demanding the distance of center of arc to RE should be smaller than a given threshold.

9.4.3.4 Wall Layer

Automatic detection of wall segments is one of core problems in 3D reconstruction of architecture drawings. The most popular solution is looking for line pairs that are parallel and overlapped with each other [7, 15, 18]. However, there are amounts of obstacles in 2D CAD drawings that can interfere the extraction of wall lines. The first group of obstacles attributes to structural objects that are also formed of parallel lines, such as stair, window and column. The second group of obstacles is matching a wrong parallel line from other types of lines. When a wall line is looking for its parallel line, it might match a nearby grid line which is also parallel. Hence, the wall layer classification method focuses on end of wall rather than middle part. FE is line with length greater than 100 mm and smaller than 300 mm. As discussed before, the wall width limitation is a sufficient condition. Two relative elements are two lines that intersect with two ends of FE. Also, these two RE should be perpendicular to FE. Third RE stems from the dependence relation between other structural members and wall. It is common sense that door and window are built relying on walls. Since the door and window layer classification method has been proposed in previous section, the RE is line or arc from this layer. In other words, FE would be more possibly to be a wall end line if it associates with graphical elements of door or window. Consequently, the intersection between FE and the third RE turns into a sufficient condition.

9.5 Performance Evaluation

70 2D CAD drawings are used as testing data to evaluate the accuracy of classification. On each drawing, the most possible grid text layer, dimension layer, window and door layer and wall layer are picked off using above methods. Correctness of result is verified by analyzing the practical property of sorted layer artificially. Dividing total score by number of FE in a layer, average score of FE is generated in order to reflect the similarity between FE and targeted object. And average total score shows the ordinary maximum total score of a layer in the test, and its value is closely related to quantity of FE and score that every FE obtains with regard to a category.

As shown in Table 9.2, the average scores of grid text layer and dimension layer are relatively higher than that of window and door layer and wall layer, which are above 0.5. It suggests that when recognizing FE of these two layers, the system has more confidence that FE is part of grid text or dimension symbol. As a result, the higher average score brings about higher accuracy of classification. In 70 drawings, the classification system successfully sorted out the two layers without mistakes. In comparison, the accuracy of selecting the rest two layers are about 95 and 85% respectively. In terms of window and door layer, the error results from a drawing putting door symbols on two layers. This drawing has been modified twice in the design stage, and the added elements including new doors in the second turn of modification were placed on a particular layer. The degree of correction on wall layer recognition is the lowest among testing layers. It attributes to the system misdeems column layer for wall layer. In 2D drawings, the contour of column is similar with wall, but it is more frequently located around grid points [14]. Therefore, it is significant to identify column layer before wall layer so that accuracy can be improved.

In general, the overall performance of the layer classification method is optimistic except for wall layer recognition. The average correction rate is around 95% and average time for running algorithms takes up 0.5–2 min depending on scale of drawing. The results suggest that the method could be efficient when input 2D CAD drawings is well-organized. Further adjustment would address on the optimization of NC/SC design and order of recognition such as column and wall.

Table 9.2 Testing result of layer classification

Layer category	Avg. score	Avg. total score	Accuracy (%)
Grid text	0.694	44.220	100
Dimension	0.666	50.1354	100
Window and door	0.567	45.243	97.96
Wall	0.298	68.286	85.7

9.6 Value of Automated Layer Classification

Substantially, automated layer classification is a pretreatment of 3D reconstruction of 2D drawings. It sorted out valid layers with clear property. Based on automated layer classification, each structural object and annotation can be detected and modeled within its resident layer. Therefore, the accuracy of existed recognition algorithms can be effectively improved as disturbance is removed. In addition, some completed modelling algorithms are written in a complicated structure. As a result, the computation cost is high, and it's difficult to meet the configuration requirement of computers in many design institutes and construction companies. Automated layer classification can relieve pressure on computation to some extent. Even though it wastes time to operate automated layer classification codes at the beginning, the entire time spent on transforming 2D drawings to BIM models is reduced because less data is inputted into latter complex algorithms.

One issue addressed on the current commercial products of transforming CAD drawings to BIM model is that they can only process floor plan views but ignore section views which contains important information relevant to height. The hardship on recognition of section drawing results from complexity of geometry. In contrast to plan view, section view is drawn closer to the realistic appearance of building rather than presenting structural objects by conventional symbols. However, it is feasible to detect structural member by layer information rather than shape parameters. A prerequisite is constructing a global coordinate system to integrate different views of building. Lu et al. [14] published SINIHIR model that merges dimension and grid line to form several local coordination systems, and then selects one benchmark to transform all local coordination systems into a unified global system. Based on his model, the exact coordination of every detected elements in floor plan can be obtained. After that the same position is located in section view. Instead of conducting geometry and semantic analysis, intended object is distinguished by searching graphical elements with identical layer of the structural element. As a result, height information is acquired from section view. The detailed method of recognition of section drawings can be further explored.

The main contribution of this method addresses on improving automation level of current conversion algorithms. A state-of-art transform method proposed by Dominguez and his colleagues [7] requires selecting layer manually. Using automated layer classification, their method can switch from semi-automation to full-automation. The secondary contribution of this method is improving accuracy as well as reducing computation cost for some comprehensive algorithms. The SINEHIR method proposed by Lu et al. [14] can be used to recognize dimensions, coordinate system and structural components at the same time but the accuracy is not high. Automated layer classification can decrease SINEHIR method's recognition computation cost and subsequently improve correction rate. The third contribution is that the method provides a potential of multi-view recognition. Current commercial product can only process plan view. The adoption of automated layer classification make section view identification become possible.

9.7 Conclusion

In this paper, the status of BIM development in China is stated and one key issue is addressed, which is a waste of time and money on transforming CAD to BIM models manually. Then construction structure drawing and previous 3D reconstruction of architecture floor plans are studied. To make up for shortcomings, an automated layer classification method is proposed as a pretreatment in the process of 3D reconstruction.

Layer property in construction structure drawings is firstly investigated by reviewing standards and real-life CAD drawings. It is found that naming format of layer in real-life drawings does not strictly follow international standards but accords to enterprise-level specifications. However, all 2D drawings put one category of objects in one layer, so the contents remain constant. Hence, the layer classification method uses geometry and topology content in each layer to identify its property. The classification checks attributes of feature element specific to a category, and subsequently checks its related elements. The conditions on FE and RE are grouped into necessary conditions and sufficient conditions. This division method results from some drawing conventions are rigid while others are loose. Finally, the layer with maximum total score is recognized as the targeted layer. Based on this structure, detailed method of classifying grid text layer, dimension layer, window and door layer and wall layer are discussed. The testing result shows high recognition rate in the first three categories. But the accuracy of classifying wall layer is only 85% due to the interference of column layer. Further adjustment should focus on the order of classification and setting more reasonable conditions.

Assisted by layer classification, the accuracy and automation degree of existed recognition and modelling algorithms can be improved because disturbance from irrelevant layers is eliminated. In addition, layer classification system is expected to expert effects on section view recognition combined with global axis coordinate system.

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